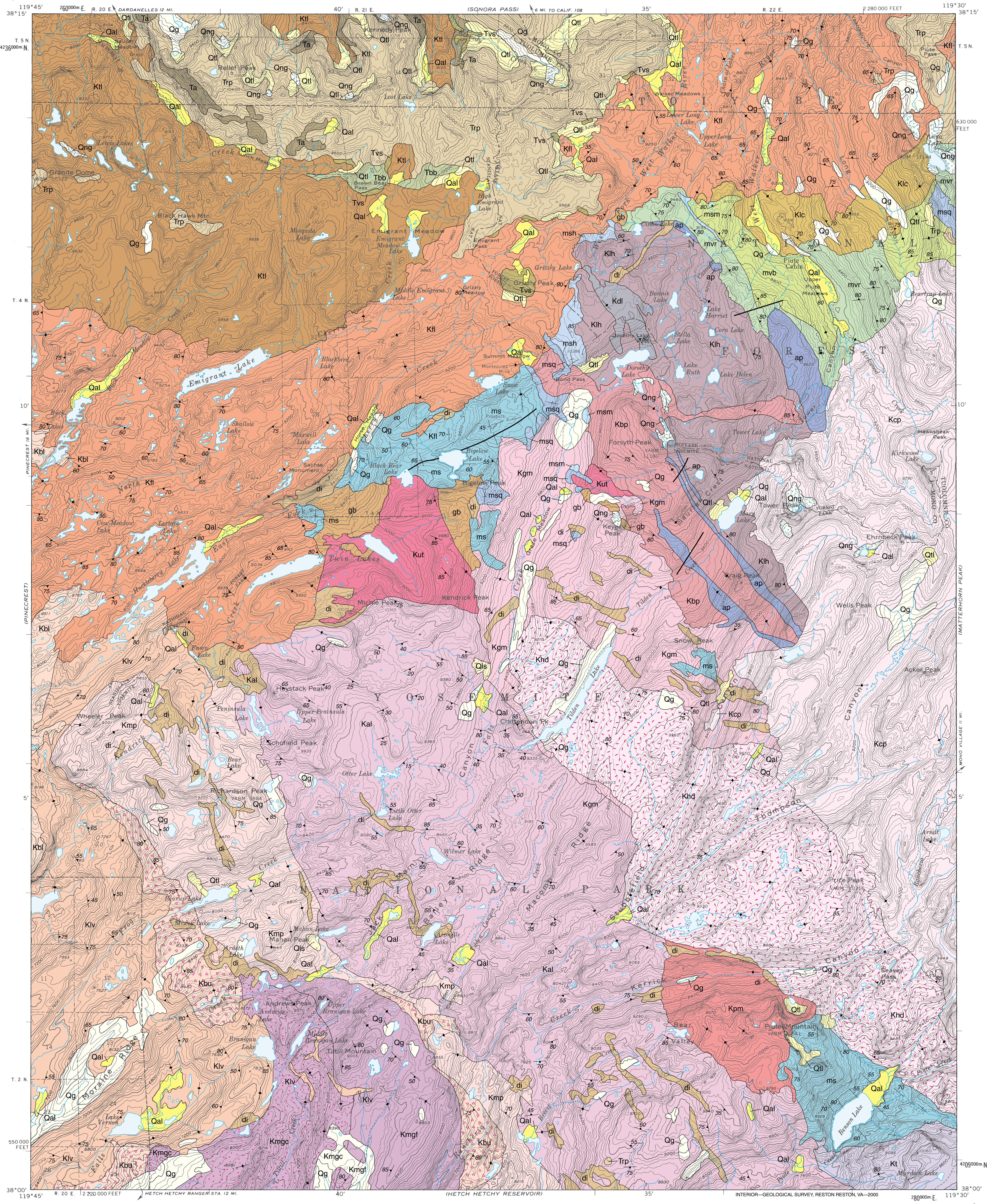
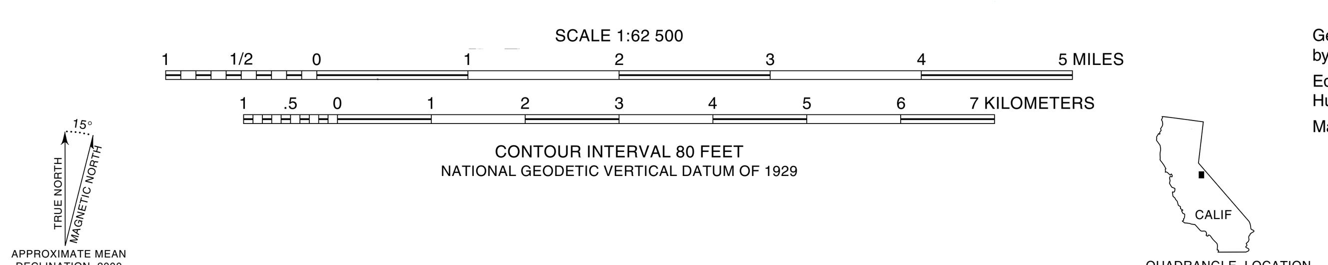


Base from U.S. Geological Survey, 1956
10,000-foot grid based on California coordinate system, zone 3
1000-meter Universal Transverse Mercator grid ticks, zone 11

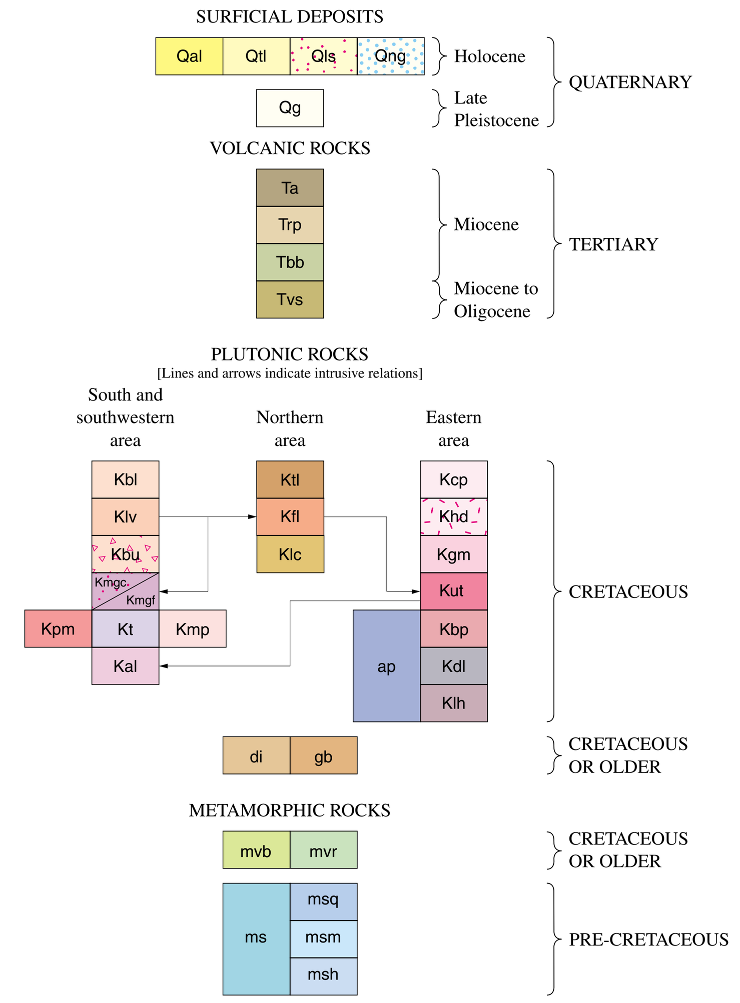


Geology by Clyde Wahrhaftig, 1955-80; compiled by N. King Huber, 1998
Edited by Jane S. Ciener; digital cartography by Hugh F. Thomas and Darlene A. Casebier
Manuscript approved for publication July 7, 1999

GEOLOGIC MAP OF THE TOWER PEAK QUADRANGLE, CENTRAL SIERRA NEVADA,CALIFORNIA

By
Clyde Wahrhaftig
2000

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Qal **Alluvium (Holocene)**—Chiefly sand and gravel underlying meadows

Qtl **Talus (Holocene)**—Rock waste derived from cliffs. Only especially extensive areas shown

Qls **Landslide deposits (Holocene)**—Unsorted debris deposits resulting from mass movement

Qng **Neoglacial and periglacial deposits (Holocene)**—Includes cirque moraines and rock glaciers

Qg **Glacial deposits (late Pleistocene)**—Chiefly morainal deposits from Tioga-age glaciation, but includes some of probable Tahoe age in southwestern corner of quadrangle

VOLCANIC ROCKS

Ta **Hornblende andesite and basalt (Miocene)**—Dark gray andesite, with conspicuous hornblende needles, and basalt; occurs as dikes, sills, and irregular masses intrusive into and probably related to the Relief Peak Formation

Trp **Relief Peak Formation (Miocene)**—Mainly lahars with porphyritic hornblende andesite clasts and some lava flows. Includes interbedded stream deposits. In quadrangles to the west and northwest, unit underlies Table Mountain Latite, whose K-Ar age is about 9.5 Ma (Dalrymple, 1964)

Tbb **Basalt of Brown Bear Pass (Miocene)**—Light- to dark-gray, massive basalt with vertical columnar jointing. Highly vesicular facies and purplish autobrecciated facies also present. Overlies Valley Springs Formation, but relationship to Relief Peak Formation is unclear. Unit has K-Ar ages of 19 to 20 Ma (Robinson and Kistler, 1986)

Tvs **Valley Springs Formation (Miocene to Oligocene)**—Rhyolite tuff, partly to densely welded, and bedded ash deposits. Locally includes rhyolitic sedimentary deposits. Unit has K-Ar ages of 24 to 27 Ma in Dardanelles Cone quadrangle to northwest (Robinson and Kistler, 1986)

PLUTONIC ROCKS

South and southwestern area

Kbl **Granodiorite of Boundary Lake (Cretaceous)**—Light-colored, medium-grained biotite granodiorite and granite characterized by discrete anhedral quartz grains. Locally porphyritic with varying proportions of plagioclase and small tabular K-feldspar phenocrysts

Klv **Granodiorite of Lake Vernon (Cretaceous)**—Hornblende-biotite granodiorite characterized by bimodal grain-size distribution of mafic minerals, with scattered grains 5 mm to 1 cm in size, and abundant grains 1 mm in size and smaller, giving the rock a "spotted" appearance. Contains numerous flattened mafic inclusions. Equivalent to granodiorite of Tueeulala Falls of Dodge and Calk (1987), part of granodiorite of Boundary Lake of Huber (1983), and part of the quartz diorite of Mount Gibson of Kistler (1973)

Kbu **Granodiorite of Bearup Lake (Cretaceous)**—Even-grained granodiorite characterized by euhedral hornblende and biotite crystals and with a wide range in mafic mineral content. Equivalent to part of quartz diorite of Mount Gibson and part of granodiorite of Double Rock of Kistler (1973)

Quartz diorite of Mount Gibson (Cretaceous)—Dark-gray, pyroxene-bearing quartz diorite, commonly with large poikilitic biotite crystals and locally with rare orbicules. Composed of two facies. The contact between the facies is sharp, with the coarse-grained facies intruding the fine-grained facies

Kmgc **Coarse-grained facies**

Kmgf **Fine-grained facies**

Kpm **Granite of Piute Mountain (Cretaceous)**—Light-pink to orange, medium- to coarse-grained granite containing abundant, closely packed, tabular microcline crystals

Kt **Leucogranite of Ten Lakes (Cretaceous)**—White, coarse-grained leucogranite mottled by gray anhedral quartz crystals. Quartz, microcline, and plagioclase in equal proportions; mafic mineral content about 4 percent

Kmp **Complex of Mahan Peak (Cretaceous)**—Strongly foliated and migmatitic complex of fine-grained leucogranite with abundant diorite inclusions and cut by unfoliated, fine-grained granitic dikes and irregular masses. Equivalent to part of granodiorite of Double Rock of Kistler (1973)

Kal **Granite of Avonelle Lake (Cretaceous)**—Coarse-grained biotite granite, commonly with abundant tabular phenocrysts of microcline as much as 3 cm in maximum dimension. Equivalent to granodiorite of Rancheria Mountain and part of granodiorite of Double Rock of Kistler (1973)

Northern area

Ktl **Granodiorite of Topaz Lake (Cretaceous)**—Light-gray, coarse-grained biotite granodiorite and granite with roughly equant, well-formed microcline phenocrysts as much as 10 cm long making up 2 to 10 percent of the rock. Quartz typically occurs in 1/2-cm clots. Mafic mineral content about 10 percent. Asymmetric schlieren locally abundant

Kfl **Granodiorite of Fremont Lake (Cretaceous)**—Medium-dark-gray, medium-grained, hornblende-biotite granodiorite. Where hornblende-rich, contains abundant lenticular or elongate mafic inclusions, commonly uniformly distributed, but locally in clusters. In the southwest part of its occurrence in this quadrangle, it is largely mafic free, lacking in inclusions, and tending toward granitic composition. Map unit is named for exposures near Fremont Lake where it was mapped by Giusso (1981) in the Sonora Pass quadrangle to the north. The unit extends west into the Pinecrest quadrangle where it has been called the granodiorite of Kinney Lakes (Huber, 1983)

Klc **Granodiorite of Long Canyon (Cretaceous)**—Dark hornblende-biotite granodiorite and quartz-diorite with mafic mineral content of about 30 percent and with abundant mafic inclusions

Eastern area

Kcp **Cathedral Peak Granodiorite (Cretaceous)**—Medium- to coarse-grained, hornblende-biotite granodiorite that contains conspicuous blocky phenocrysts of microcline as much as 10 cm long. The phenocrysts commonly occur in aligned swarms and asymmetric schlieren are locally abundant

Khd **Half Dome Granodiorite (Cretaceous)**—Medium- to coarse-grained, equigranular hornblende-biotite granodiorite with abundant elongate or flattened mafic inclusions. Characterized by euhedral hornblende prisms as much as 1 cm long, biotite books as much as 1 cm across, and conspicuous sphene. Near Tilden Lake it is mafic-poor and has large microcline phenocrysts

Kgm **Alaskite of Grace Meadow (Cretaceous)**—Sugary, medium- to fine-grained, light-pink to white alaskite with rare dark minerals. Contains abundant inclusions of diorite, gabbro, quartzite, biotite schist, and marble

Kut **Granite of Upper Twin Lake (Cretaceous)**—Coarse, equigranular, pink biotite granite. Locally has a very strong vertical lineation, probably of metamorphic origin

Kbp **Granite of Bond Pass (Cretaceous)**—Gray, moderately foliated, hornblende-biotite granite and granodiorite with moderately large, slightly pinkish, K-feldspar phenocrysts. Locally intensely sheared. Includes bodies of aplite or fine-grained sugary alaskite containing tourmaline rosettes and mapped separately

Kdl **Granite of Dorothy Lake (Cretaceous)**—Light-pink, fine- to coarse-grained tourmaline-bearing granite. Contains rare miarolitic cavities. Locally intensely sheared, with tourmaline on shear surfaces

Klh **Granodiorite of Lake Harriet (Cretaceous)**—Dark-gray, moderately foliated granodiorite characterized by shreddy clots of biotite and hornblende. Aplitic border facies along northeastern margin mapped separately

ap **Aplite (Cretaceous)**—In granodiorite of Bond Pass (Kbp) occurs as dike-like bodies of aplite or fine-grained sugary alaskite containing tourmaline rosettes. Includes aplitic border facies of granodiorite of Lake Harriet (Klh) mapped along the northeastern margin of that pluton

di, gb **Diorite and gabbro (Cretaceous or older)**—Occurs as generally small, irregularly shaped bodies throughout the map area. Extremely variable in grain size, texture, and composition. Some bodies are older and some younger than the plutonic rocks with which they are in contact, but most appear to be xenoliths. Two larger bodies of coarse-grained hornblende gabbro (gb), near the center of the quadrangle, intrude the metasedimentary sequence and in turn also have been metamorphosed. This coarse-grained gabbro has a U/Pb zircon age of about 148 Ma (Lahren and others, 1990)

METAMORPHIC ROCKS

mvb **Basaltic metavolcanic rocks (Cretaceous or older)**—Basaltic and andesitic metavolcanic rocks derived from lava flows and tuffs. Includes associated dark metasedimentary rocks

mvr **Rhyolitic metavolcanic rocks (Cretaceous or older)**—Rhyolitic and dacitic metavolcanic rocks derived from tuffs, some probably ignimbrites. Includes metarhyolite breccia and possibly some metamorphosed intrusive rocks

ms, msq, msm, msh **Metasedimentary rocks (pre-Cretaceous)**—Includes quartzite, marble, biotite-andalusite schist, meta-conglomerate, and calc-silicate hornfels. Predominate rock type indicated in local areas: msq, commonly pure, white, crossbedded quartzite; msm, white to gray, medium- to coarse-grained marble; msh, fine-grained calc-silicate hornfels

Contact

Fault

Strike and dip of bedding
65 Inclined
Vertical

Strike and dip of foliation
65 Inclined
Vertical

PREFACE

Clyde Wahrhaftig mapped the geology of the Tower Peak quadrangle in great detail (scale 1:24,000) over a period of many years from 1955 to 1980. For use in preparing a geologic map of Yosemite National Park (Huber and others, 1989), he reduced and generalized his geology to a scale of 1:48,000. Clyde died before he could complete a 1:62,500 version to match other published 15-minute geologic quadrangles in the park. Consequently, the present version was compiled by N. King Huber from materials left by Clyde and from geologic information from adjacent quadrangles. It is hoped that the result does not seriously compromise Clyde's interpretations. Publication of the map was supported by a contribution from the Clyde Wahrhaftig Trust.

PLUTONIC AND METAMORPHIC ROCKS OF THE TOWER PEAK QUADRANGLE

[The following text is from a draft prepared by Wahrhaftig and all of the interpretations are his. It has been slightly rearranged and edited by N. King Huber.]

INTRODUCTION

The Tower Peak quadrangle, which includes northernmost Yosemite National Park, is located astride the glaciated crest of the central Sierra Nevada and covers an exceptionally well-exposed part of the Sierra Nevada batholith. Granitic plutonic rocks of the batholith dominate the geology of the Tower Peak quadrangle, and at least 18 separate pre-Tertiary intrusive events have been identified.

Pre-Cretaceous metamorphic rocks crop out in the quadrangle in isolated roof pendants and septa. Tertiary volcanic rocks cover granitic rocks in the northern part of the quadrangle, but are not considered in this brief summary. Potassium-argon (K-Ar) age determinations for plutonic rocks in the quadrangle range from 83 to 96 million years (Ma), including one of 86 Ma for the granodiorite of Lake Harriet (Robinson and Kistler, 1986). However, a rubidium-strontium whole-rock isochron age of 129 Ma has been obtained for the Lake Harriet pluton (Robinson and Kistler, 1986), which field evidence indicates is the oldest plutonic body within the quadrangle. This suggests that some of the K-Ar ages record resetting during later thermal events and are too young. The evidence indicates that all the plutonic rocks are of Cretaceous age, with the youngest being the Cathedral Peak Granodiorite at about 83 Ma.

The pre-Tertiary rocks of the Tower Peak quadrangle fall into two groups: (1) an L-shaped area of older plutonic and metamorphic rocks, 3 to 10 km wide, that extends diagonally both northeast and southeast from near the center of the quadrangle; and (2) a younger group of large, probably composite intrusions that cover large areas in adjacent quadrangles and extend into the Tower Peak quadrangle from the east, north, and southwest.

OLDER PLUTONIC AND METAMORPHIC ROCKS

The L-shaped remnant of older plutonic and metamorphic rocks that extends northeast and southeast from the center of the quadrangle contains ten plutons with contiguous areas of at least 2.5 sq. km and several complexes of dikes and small irregular masses. These plutons and dikes intruded silicic and mafic metavolcanic rocks and miogeoclinal metasedimentary rocks. Mutual age relations between the plutonic rocks are incompletely determined, either because some of the rocks are not in geographically contiguous sequences or because the contacts have ambiguous age criteria. Structures in this remnant are generally steep, trend northwesterly, and are cut off sharply by the younger plutons. Lineations, foliations, and zones of recrystallization and shearing, all of supposed metamorphic or tectonic origin, are present in some plutons and suggest at least one period of dynamic metamorphism during or after the period of emplacement of these plutons. The metamorphic and early mafic rocks are described first below, followed by the plutonic rocks of the northeast arm of the "L", and then the rocks of the southeast arm.

Metamorphosed sedimentary rocks appear to be the oldest rocks. They include pure white orthoquartzite, in beds a few meters thick, that display thin partings bearing andalusite and biotite and common internal crossbedding. These are interbedded with thick (10 to 50 m) units of biotite-andalusite-sillimanite(?) schist, coarsely crystalline marble, and fine to coarse beds of pale-green, calc-silicate hornfels. These metasediments are complexly deformed. The southern body around Benson Lake is mainly quartzite, with some thick biotite-andalusite schist bodies near the top and marble at the base, folded into a large anticline with a horizontal crest and vertical limbs. The minimum stratigraphic thickness exposed in this body is 750 m. The northern body, around Bigelow and Snow Lakes, contains abundant marble bodies and about equal amounts of quartzite, biotite schist, and calc-silicate hornfels. It has been folded at least twice, the first time isoclinally. The latest deformation was into a flat-topped dome with nearly vertical flanks along the intrusive contacts. Small bodies and inclusions of metasedimentary rocks in several of the plutons indicate that this terrane was once more widespread. In the extreme northeast part of the quadrangle, metasedimentary rocks, which may be in depositional sequence with the metavolcanic rocks, include quartzite and stretched conglomerate.

[The metamorphic rocks in the Snow Lake region (Snow Lake pendant) have been extensively studied by Mary M. Lahren, who has correlated them with Precambrian to Triassic formations exposed in southeastern California (Lahren, 1989; 1991; Lahren and Schweickert, 1989). No attempt has been made here to reconcile Wahrhaftig's earlier mapping with her later interpretations.]

Bodies of diorite and hornblende-gabbro appear to be the oldest intrusions in the metasedimentary sequence. The gabbro contains bodies of pure hornblendite or hornblende-pyroxene rock as much as 300 m across. Hornblende crystals in these pods are as much as 3 cm across and are generally stubby or equant. Some of the gabbro in the large body near the center of the quadrangle shows tilted but right-side-up cumulate layering. All the mafic and ultramafic rocks have been metamorphosed.

Next younger seems to be a differentiated plutonic complex that includes the granodiorite of Lake Harriet, with an aplitic border facies, and the granite of Dorothy Lake. The Lake Harriet and its aplitic border facies intrude the metarhyolite, which is interpreted to be an ignimbrite because the outlines of flattened pumice fragments can be seen on weathered outcrops. The Dorothy Lake appears to be a siliceous core to the Lake Harriet pluton.

Intrusive into the Lake Harriet complex is the granite of Bond Pass, which was intruded in turn by the granite of Upper Twin Lake, and that by the alaskite of Grace Meadow. The Bond Pass is cut by northwest-trending, dike-like bodies of aplite that contain spherical rosette-like intergrowths of tourmaline, quartz, and feldspar. The granite of Upper Twin Lake has in places an intense vertical lineation expressed as a lengthening of quartz and feldspar grains, which is probably metamorphic in origin. The Grace Meadow lacks these metamorphic structures, at least on the mesoscopic scale. This implies a period of tectonism affected the above sequence just prior to the Grace Meadow intrusion.

The alaskite of Grace Meadow has the geographic pattern of a sheath enclosing the northwest end of the Half Dome Granodiorite pluton, suggesting that the Half Dome was emplaced by stoping the core of the Grace Meadow. The Grace Meadow has the peculiarity that although it is relatively uniformly leucocratic in color index, it contains abundant, irregularly distributed, large and small inclusions of gabbro, diorite, and metasedimentary rocks, many large enough to show on the geologic map. These inclusions appear to define belts through the Grace Meadow that before the intrusion might have been largely metasedimentary or largely mafic intrusive rocks. Although the contacts of the Grace Meadow with all older rocks are clearly intrusive, suggesting magmatic stoping, the impression given by the abundant inclusions is one of relatively passive emplacement with little large-scale fluid flow within the pluton. Perhaps the magma was injected initially as a dike complex along fractures in a shattered mafic and metamorphic complex, and the dikes simply widened out to form the present pluton as the fragments of older rocks drifted apart and downward. The inclusions also indicate that if the older plutons, such as the granite of Bond Pass and granite of Upper Twin Lake, were present where the Grace Meadow now is, they were completely dissolved in the new magma.

The granodiorite of Long Canyon, in the northeast corner of the quadrangle, is a mafic granodiorite that intrudes metavolcanic rocks and is intruded in turn by the granodiorite of Fremont Lake. Its geographic position suggests that it might be an early mafic member of the Fremont Lake-Topaz Lake intrusive sequence, but it appears to have been affected by a period of deformation that predates the intrusion of the Fremont Lake. This deformation has produced boudinage of dikes and mineral foliation at considerable angles to intrusive contacts. Hence the Long Canyon pluton may be much older than the above intrusive sequence.

The southeast branch of the L-shaped area of older rocks is dominated by the granite of Avonelle Lake, which contains abundant euhedral to subhedral, tabular-shaped K-feldspar phenocrysts as much as 3 cm in maximum dimension. The Avonelle Lake pluton extends south into the Hetch Hetchy Reservoir quadrangle, where it is probably equivalent to the granodiorite of Double Rock (Kistler, 1973). However, difficulties in matching contacts and lithologic descriptions across the quadrangle boundary make this correlation tentative and require a separate rock-unit name to avoid future confusion. The contact of the Avonelle Lake with the granite of Upper Twin Lake has given conflicting evidence for their relative ages, but there is a strong indication that the Upper Twin Lake is younger.

The granite of Avonelle Lake is intruded on the northeast by two relatively small plutons. The granite of Piute Mountain contains much more abundant, but smaller, flattened K-feldspar phenocrysts and has sharp intrusive contacts with a fine-grained gray selvage against the Avonelle Lake. The leucogranite of Ten Lakes (termed alaskite by Kistler, 1973, in the adjacent Hetch Hetchy Reservoir quadrangle) is coarse grained and mottled by gray anhedral quartz crystals. Both of these latter plutons are intruded by rocks of the Tuolumne Intrusive Suite, part of the younger group of plutons.

On its southwest margin the granite of Avonelle Lake is intruded by a strongly foliated complex of leucogranite containing abundant diorite inclusions and cut by unfoliated, fine-grained granite dikes and irregular masses. This complex is mapped as the complex of Mahan Peak. It is continuous with the granodiorite of Rancheria Mountain of Kistler (1973). The complex is clearly intruded by the granodiorite of Lake Vernon (the "spotted rock"). Its contact relations with the quartz diorite of Mt. Gibson and the granodiorite of Bearup Lake are equivocal, but a locality near the trail from Jack Main Canyon (Paradise Valley) to Tiltill Mountain has inclusions of the Mahan Peak complex in the Mt. Gibson pluton. The simplest, but not completely satisfactory, explanation for the Mahan Peak complex is that it represents granite of Avonelle Lake together with contained diorite dikes that were remobilized and partly melted by the intrusion of the quartz diorite of Mt. Gibson, whose emplacement temperature would have been considerably higher than that of the granite of Avonelle Lake.

YOUNGER PLUTONIC ROCKS

The eastern composite intrusion of the younger group is the Tuolumne Intrusive Suite. In the Tower Peak quadrangle, the Tuolumne Suite includes (1) the northernmost and westernmost extent of the Cathedral Peak Granodiorite, which here has burst its shell of more mafic differentiates and intrudes older granitic and metamorphic rocks, and (2) the Half Dome Granodiorite, which is interpreted as an earlier, more mafic differentiate of the same magmatic pulse as that for the Cathedral Peak Granodiorite.

The northern composite intrusion of the younger group includes the granodiorite of Topaz Lake, a rock almost identical in appearance and age to the Cathedral Peak Granodiorite, but separated from the latter by a 6- to 7-km septum of older rocks. The Topaz Lake pluton is bordered on the south by the granodiorite of Fremont Lake. The Fremont Lake pluton appears to bear the same relationship to the granodiorite of Topaz Lake that the Half Dome Granodiorite does to the Cathedral Peak Granodiorite.

The southwestern composite intrusion of the younger group includes four large plutons in the southwest corner of the Tower Peak quadrangle and in adjacent quadrangles. These plutons show some evidence of being consanguineous, yet other evidence suggests a significant hiatus in the sequence. The complex includes, from oldest to youngest, the quartz diorite of Mt. Gibson, the granodiorite of Bearup Lake, the granodiorite of Lake Vernon, and the granodiorite of Boundary Lake. A swarm of fine-grained diorite dikes cuts the Mt. Gibson and Bearup Lake, but is apparently cut off by the granodiorite of Lake Vernon. This succession of events suggests a time break and interval of cooling. However, the granodiorite of Bearup Lake grades in color index from very near that of the Mt. Gibson where it is in intrusive contact with the Mt. Gibson to very near that of the Lake Vernon where the latter intrudes the Bearup Lake. This suggests a genetic relationship extending across the time gap.

DIORITE DIKES

Sets of diorite dikes (not shown on the geologic map) with at least three orientations intrude the granite of Avonelle Lake, and at least one set also intrudes the quartz diorite of Mt. Gibson and granodiorite of Bearup Lake. These dikes are confined to the southwest part of the quadrangle and do not appear to occur in the northeastern part of the Avonelle Lake pluton. One set trends due north and is about vertical, another set trends northwest and is about vertical, and the third strikes roughly east-west and dips 30° to 45° north. The first two sets appear to predate the formation of the Mahan Peak complex and the intrusion of the Mt. Gibson pluton because they are found as inclusions in the former. The diorite dikes probably represent periods of crustal extension, although it is not clear how extension alone would produce a dike-swarm dipping 30° north.

Where the diorite dikes intrude granite, they are bordered by thin, discontinuous selvages of fine-grained felsic rock, generally of granitic composition, but ranging toward diorite. In addition, the dikes are cut by thin, closely spaced, and exceedingly irregular veins of the same material, which are continuous with the selvages. The selvages are probably the product of melting of the granitic wall-rock by the diorite magma, which was probably intruded at a temperature well above the melting temperature of the more felsic rocks.

MAFIC INCLUSIONS

Most of the hornblende-bearing plutonic rocks have crudely lenticular or rod-like inclusions, a few centimeters to a meter or more thick and as much as 5 meters long, of relatively fine-grained predominantly mafic minerals. These are distributed moderately uniformly through the plutons, although in a few localities the inclusions form clusters resembling schools of fish. In some plutons, especially the granodiorite of Fremont Lake and Half Dome Granodiorite, the concentration of inclusions varies greatly from place to place. The mafic inclusions are composed of the same minerals as the enclosing granitic rock, but in different proportions. Their origin remains an enigma. Current evidence favors most of the inclusions having originated as blobs of basaltic magma that were incorporated into the more felsic magma from which the granitic rocks crystallized (Bateman, 1992).

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